TÉCNICO LISBOA

Extended Abstract

Thermal rehabilitation of the facades of old buildings

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1. Introduction

This research is focused on old buildings, defined as the ones constructed before the implementation of concrete as the main buildings' structural component [1]. Since this is a broad definition, old buildings were considered in this study to be the ones constructed in the period 1755-1960. The evolution of construction of buildings from this period of time, namely in the Lisbon region, can be divided into the following stages: Pombaline construction (1755-1880); Gaioleira construction (1880-1930); and Mixed construction (1930-1960) [2]. In the first two stages, the outer walls of old buildings usually played a structural role and were normally made of stone masonry, but could also be made of brick masonry or of mixing materials (when constituted by more than one material) with high thickness, which could range normally between 0.50 m and 0.90 m [2]. However, Mixed construction represents a period of transition from traditional construction to modern buildings, with the introduction of elements of concrete (namely in floors). This resulted on changes in the typology of facades, leading to the implementation of double walls in facades, in 1950, which lost their resistant role as time went by [3, 4].

As a consequence of the increase of the global consumption of energy and greenhouse gas emissions, there is nowadays a growing awareness about the importance of adopting measures and policies to reduce the energy consumption in all business sectors. In Europe, the construction sector is responsible for 40% of the total energy consumption and for approximately 30% of greenhouse gas emissions [5].

Regarding new buildings, the Decree-Law n. 118/2013 of 20th August [6] is presently in force and demands the thermal verification of the building envelope's performance. For that reason, maximum allowable values for the heat transfer coefficient of opaque areas were defined according to the type of element of the envelope and climate winter zone (I1, I2 or I3 - being the first one the less extreme climate, and the last one the more adverse climate). However, when it comes to existing buildings, the Decree-Law n. 53/2014, of 8th April [7] provides the establishment of an exceptional and temporary procedure for urban rehabilitation, in which residential buildings or apartments, which construction has been completed at least 30 years ago or which location is inserted in areas of urban rehabilitation, are not obligated to verify the minimum requirements for energy efficiency and thermal quality if there is a properly justification, based on the existence of technical, functional, architectural or economic unfeasibility.

Nevertheless, and according to [8], any intervention of rehabilitation should always consider the possibility of thermal retrofitting, even though not being a legal obligation. This is not only important to maintain and preserve existing buildings but is, as well, very relevant to implement improvement measures that contribute to the energy efficiency and sustainability of those buildings. There are already some efforts in order to incentive the implementation of energy efficiency measures, such as the obligation to present the energy certificate whenever a real estate is for sale or for rent, whether is a new or an existing building, which purpose is to make the energy efficiency into an increasingly significant choice factor for the consumer and therefore to motivate the seller to implement those measures [9]. Besides, there are also external financial support to motivate energy efficiency interventions in buildings, such as the one offered by the Energy Efficiency Fund to finance t thermal retrofitting interventions on facades and roofs of residential buildings or dwellings built until 1990 [10].

The facades of old buildings have an interesting thermal behaviour due to their strong thermal inertia, by which they can retain heat and release it later (after 6 to 8 hours), allowing the interior space of the buildings to have lower thermal fluctuations [11]. However, these facades do not have any type of thermal insulation solution included, since these buildings were constructed before any thermal regulation had been implemented, and before there were concerns in terms of establishing thermal requirements for buildings in the construction sector, resulting in envelopes with poor thermal resistance [12].

Therefore, thermal rehabilitation is very important and should be applied in these facades, because it provides them with a better thermal resistance to heat exchanges, thus ensuring thermal comfort conditions in the interior space and reducing the energy consumption through heating and cooling [13]. In fact, according to [1], old buildings' envelope cannot comply with the thermal requirements demanded by nowadays' users, and with the indoor comfort temperature of 18°C in winter, without resorting to a reinforcement of their thermal performance. Furthermore, the application of thermal insulation combined with proper ventilation of the indoor space is an important measure to prevent the occurrence of surface condensations on outer walls [1]. There are many thermal insulation solutions in the market. Their potential application on facades of old buildings has to be analysed in order to determine which solution better suites the restrictions that characterize each case. Table 1 summarizes the solutions for thermal rehabilitation of facades.

Table 1: Thermal retrofitting solutions for facades

Position of the thermal insulation	Type of thermal retrofitting solution
External thermal insulation	External Thermal Insulation Composite System (ETICS)
	Ventilated Facade
Thermal insulation inside the cavity of double-leaf walls	Injection of insulation product in granules
	Injection of insulating foam (expanded on-site)
Internal thermal insulation	Internal Thermal Insulation Composite System (ITICS)
	Prefabricated insulating boards with adherent coating
	Counter-wall on the inner side wall: • Counter-wall of light brick masonry • Counter-wall of gypsum plasterboards
External or internal cladding of the facade	Mortar with improved thermal performance

2. Summary on the advantages and disadvantages of thermal retrofitting solutions for facades

In this study, the advantages and disadvantages of each thermal retrofitting solution was search for in reference literature, in order to: determine which solution should be applied based on the restrictions of each type of intervention; compare with the decisions made in practical cases of real rehabilitations. Table 2 presents the summary of the research made in this study.

3. Field work

The aim of the field work carried out in this study was, first of all, the analysis of the reality of the construction sector when it comes to the execution of a thermal rehabilitation of the facades of old buildings. It is important to understand if, nowadays, thermal retrofitting solutions are being applied on facades when the rehabilitation of old buildings occur, and, if not, which are the reasons that prevent their application. Secondly, this field work determined, for different case studies: the reasons that lead to the selection of certain thermal retrofitting solutions, over other available solutions; the advantages and disadvantages of such solutions; the constraints involved in each case study.

Table 2: Summary of the advantages and disadvantages of each thermal insulation solution for facades

Solution	Advantages	Disadvantages
ETICS	• High thermal efficiency • Correction of thermal bridges and consequent reduction of the risk of condensation • Preservation of thermal inertia • Quick and simple application in facades with few architectural features • Convenience of the occupants during the execution • The inner area remains intact • Provides an exterior aesthetic renovation • Works as a protective barrier against atmospheric agents	• There are frequently durability issues with the system's coating (presence of anomalies) • Requires maintenance works periodically • Does not allow the aesthetical preservation of buildings with architectural or heritage value • Complexity in the edge finishing execution due to architectural constraints • High investment cost • Vulnerability to mechanical stresses (impacts) • Execution exposed to the weather conditions, which can compromise the performance of the thermal retrofitting solution • Not appropriate for facades with ascending humidity and/or for very porous facades
Ventilated Facade	• High thermal efficiency • Correction of thermal bridges and consequent reduction of the risk of condensation • Preservation of thermal inertia • Convenience of the occupants during the execution • The inner area remains intact • Provides an exterior aesthetic renovation • Works as a protective barrier against atmospheric agents • Reduces the risk of internal condensations in the walls, in winter, and retains sunlight in the systems' ventilated chamber, in summer • Easy maintenance • High durability	• Does not allow the aesthetical preservation of buildings with architectural or heritage value • Complexity in the edge finishing execution due to architectural constraints • The highest investment cost • Execution exposed to the weather conditions • Risk of spread of fire between floors, because of the system's ventilated chamber, if it is not properly sectioned • The wall's support (masonry) must have sufficient resistance, stability, and cohesion.
Thermal insulation injection in the cavity of double-leaf walls	• Preservation of the original internal and external appearance of the facades • The inner area remains intact	• Does not protect the facade from outside actions caused by atmospheric agents • Reduces the thermal inertia, but does not completely eliminate it • Does not eliminate thermal bridges • Requires skilled labor, because, for instance, the injection must completely and homogeneously seal the cavity • Execution might have some complexity, depending on the facade features • The efficiency of its implementation depends on the existing conditions in the cavity
Internal thermal insulation	• Preservation of the appearance of old buildings with architectural or heritage value • Quick and easy application	• The inner area is reduced • Constraints for the occupants during its execution • Does not work as a protective barrier against atmospheric agents • Eliminates the thermal inertia of the existing wall • Does not eliminate thermal bridges
Mortar with improved thermal performance	• Easiest execution • Increase of the acoustic proprieties of the facades, highest than other retrofitting solutions • Permeability to water vapour	• Thermally less efficient than most solutions, so it can be recommended to use as a complementary solution of other thermal retrofitting solution

Therefore, this research analysed 12 case studies of rehabilitation of old buildings (built until 1960). Some of these cases include thermal retrofitting solutions applied on existing outer walls, while others do not include any thermal retrofitting solution on existing facades. Rehabilitation works included in this field work are mostly located in the District of Lisbon, with the exception of one case study, which is located in Coimbra. Furthermore, 3 interviews were conducted to experts in the field of rehabilitation, in order to obtain their opinion on the subject being studied.

4. Discussion and results

4.1 Critical analysis of the case studies with thermal retrofitting of existing facades

The following solutions were identified in these case studies: internal thermal insulation coated with gypsum plasterboards and fixed by a supporting structure, allowing the existence of a ventilated cavity between the thermal insulation and the wall (Cases A and B); External Thermal Insulation Composite System (ETICS) applied in certain places of the facades (Case C) or throughout the façade (Case D); and injection of insulating material in the cavity of double-leaf walls (Case E). These were considered to be the most economically and technically viable solutions for each case study. Table 3 summarizes the main constraints involved in each intervention, and the advantages and disadvantages associated with the chosen solutions.

Table 3: Summary of the critical analysis of case studies A to E

Summary of the critical analysis to the cases with thermal rehabilitation of existing facades					
Case Studies	**Period of construction**	**Main constraints of the building**	**Thermal retrofitting solution adopted**	**Main advantages**	**Main disadvantages**
Case A	1880-1930	Need to maintain the external appearance of the facades to preserve the architectural and heritage value of the building	Internal thermal insulation composed by MW (mineral wool) boards coated with gypsum plasterboards	Preservation of the original aesthetic of the facades	Eliminates the thermal inertia of the existing outer walls and decreases useful indoor area
Case B					
Case C			ETICS application in less visible areas		Only corrects the thermal behaviour of facades in the areas where it is applied
Case D	1930-1960	-	External Thermal Insulation Composite System (ETICS)	Exterior aesthetic renovation Highest energy efficiency	It might be disadvantage the mischaracterization of the building architecture, but in this case the need of the architectural preservation does not exist
Case E		Need to maintain the exterior aesthetic of the facades to preserve the architectural features	PUR (polyurethane foam) injection in the whole cavity	Preservation of the original internal and external appearance of the facades	Complex application and difficulty in ensuring the efficiency of the solution

It is possible to conclude that, in the rehabilitation of old buildings built between 1880 and 1930, there is normally an architectural and heritage value associated to the building that prevents the adoption of external thermal insulation solutions throughout the facades. Therefore, in case studies A, B and C, the use of external thermal retrofitting solutions of the facades is limited. However, it was possible to adopt, in cases A and B, an internal thermal insulation solution, which increases the thermal resistance of facades, as well as preserves the original exterior appearance of those buildings. However, there are disadvantages that compromises the performance of this solution, such as: the elimination of the strong thermal inertia of existing facades, which results from a thickness equal or greater than 60 cm, causing an aggravation of the indoor thermal comfort, particularly in summer; lack of correction of thermal bridges; and reduction of the indoor floor area. Therefore, it is a less efficient thermal solution compared to a solution applied in the outside. Nevertheless, it is a more viable solution for old buildings, due to the architectural constraints. In case C, the building has also an architectural and heritage value, since it is located in an area protected by UNESCO. In this case, the adopted solution is also less thermally efficient, even though being applied on the outer face of the facades, because it is applied only in certain areas, leaving the remaining part of the facades without any kind of thermal retrofitting solution. Therefore, the envelope cannot present a good overall thermal performance.

In buildings built between 1930 and 1960, as the one in case D, there is normally more freedom to change the appearance of the facades, because there are not the constraints presented in cases A, B and C, whose authenticity and historical identity must be preserved. This allowed, in case D, the use a more thermally efficient solution, as the External Thermal Insulation Composite System (ETICS). Even though the building from case E was built between 1930 and 1960, its exterior aesthetic and architectural features had to be preserved. As so, it was possible to take advantage of the fact that the facades are composed by double-leaf walls and to inject insulating material in the cavity. Therefore, it was possible to maintain the outside and inside appearance of the outer walls, but the injection process has to be carefully made, due to the risk of compromising the performance of the thermal solution.

There were, though the filling of the inspection sheets, pointed out several other characteristics associated with the thermal insulation solutions by the technical professionals responsible for the rehabilitations in study. However, it is possible to perceive between Tables 2 and 3 that the main constraints of the analysed buildings that leaded to the adopted thermal retrofitting solution in each case, as well as the main advantages and disadvantages of these solutions, are in agreement with the literature review.

4.2 Critical analysis of the case studies without thermal retrofitting of existing facades

In case studies F to L, no thermal retrofitting solutions were considered in the rehabilitation of existing facades. Table 4 summarizes the similarities identified in these case studies, using the information gathered in the field work.

Table 4: Summary of the critical analysis of case studies F to L

Summary of key data collected from case studies without thermal insulation of existing façades							
Case studies	High thermal inertia of existing facades*	New facades with thermal insulation applied	Application of thermal insulation on the roof		Thermal correction of glazed areas	The thermal regulation was followed	Acoustic concern more relevant than thermal concern
			New construction	Existing structure			
F	x	x	x		x		x
G	x	x	x		x	x	x
H	x	x	x		x	x	x
I		x	x		x	x	
J	x	x	x		x	x	x
K	x		x		x		
L	x			x	x		x

* Main reason given to avoid applying a thermal insulation solution on existing facades.

From Table 4 it can be concluded that, in most of the case, none measure had been taken to improve the thermal performance of existing facades because there is a perception that existing facades already have a good thermal behaviour thanks to their thickness (which can vary between 0.40 m and 1 m). In other words, the strong thermal inertia of existing facades of these old buildings (built before 1930) is the main reason, in these cases, for not executing thermal retrofitting solutions and for just applying thermal insulation in new building elements, such as new facades and roofs. Furthermore, and since the roof and glazed areas are the most thermal fragile elements of the envelope, there is a more current thermal intervention in these elements. The acoustic concern also incentives the replacement of the elements of glazed areas.

4.3 Comparative analysis between the values of the heat transfer coefficient from thermal design projects and the maximum values imposed by thermal regulation

Figure 1 presents the comparison between the values of heat transfer coefficient (U) calculated for each constructive solution of the facades of case studies A and I and the maximum values imposed by thermal regulation. Existing facades with a thermal retrofitting solution (Facades 1 to 4 in case study A), and the new facades built in case I with thermal insulation solutions (Facades 3 and 4), have lower U-values than existing facades without any thermal retrofitting solution on case I (Facades 1, 2 and 5). Therefore, the thermal rehabilitation can improve the thermal performance of existing or new facades of old buildings.

The buildings of these case studies are located in Lisbon (classified as a climate zone I1). The U-values of existing facades without thermal insulation, from case I, are able to verify the maximum value of 1.8 [W/m^2.°C], which was imposed by the thermal regulation of 2006, for this climate zone, with the exception of Facade 5 from Case I: it has 0.20 cm of thickness, which is lower than typical facades of old buildings, which thickness can vary between 0.40 cm and 1 m, according to the case studies analysed in the field work. The U-values of these facades can also verify the maximum value of 1.75 [W/m^2.°C], which was imposed by the thermal regulation of 2013, which was the regulation in force by the time of case I rehabilitation. However, thermal requirements have been increasing and the current regulation, which is in force since 2015, imposes a maximum value of U of 0.5 [W/m^2.°C]. Therefore, the thermal performance of existing facades without thermal insulation, from case I, cannot accomplish current maximum allowable values. Existing facades with thermal insulation, from case A, are however able to verify the maximum value of U of 0.5 [W/m^2.°C] imposed by the current thermal regulation.

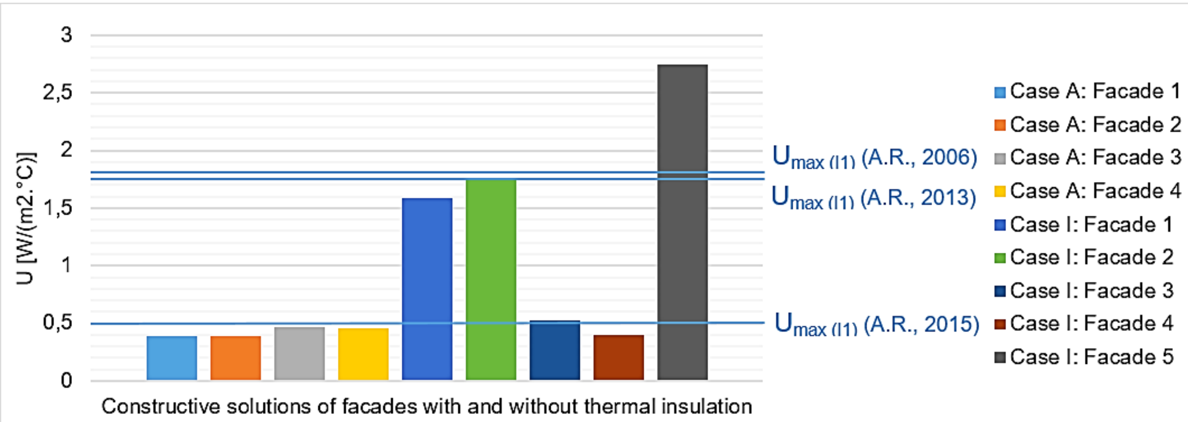

Figure 1: Comparison between the values of the heat transfer coefficient (U) of each constructive solution of the facades from case studies A and I and the maximum values imposed by thermal regulations

4.4 Information gathered in the interviews conducted to experts in the field of rehabilitation

From the information gathered in the interviews, the following briefly conclusions can be reached:

- Thermal rehabilitation is important and should be made, but it is also important that heritage preservation and technical and functional improvement of the buildings are fairly balanced;

- A significant part of the population lives with temperatures (higher/lower) that are different from comfort temperature, for energy-saving reasons, leading to a consumption of about 10% of expected energy consumption;
- Old buildings normally have a heritage and architectural value, which prevents the application of ETICS, even though it is one of the most thermally efficient solutions;
- An internal thermal retrofitting solution improves the thermal resistance of the facades, leading to a better thermal performance of the facades in winter, however it removes the usually strong thermal inertia of the facades of old buildings, leading to an overheating of the inner space of the building, in summer;
- The application of mortar with improved thermal performance can be interesting, particularly when existing coating has to be removed, however is still less thermally efficient than the other solutions.

5. Decision-support model

In the field work carried out in this dissertation, many case studies and interviews were analysed, which lead to the conclusion that measures to encourage thermal rehabilitation and to encourage more accuracy in the choice of a thermal retrofitting solution must be taken. Therefore, it is recommended the use of the decision-support model proposed, developed though the flowchart presented in Figure 2, in order to achieve these goals. The flowchart presented has critical decision points which are supported by Table 5. This table presents additional information about each decision point, assisting the selection process.

6. Conclusions and future developments

In short, it can be concluded that there is still much to do in Portugal in relation to the thermal rehabilitation of facades of old buildings and in this sense with this Dissertation it was intended to make a contribution to the development of that area, by analyzing the issues that must be considered in the process of determination of which measures should be adopted in a rehabilitation in order to improve the thermal behavior of facades of old buildings, though the determination of the constraints involved in old buildings that should be considered in this process and the advantages and disadvantages of the application of several thermal retrofitting solutions, though the study of real rehabilitation cases which gave a perception about the actual reality related to the viability of thermal rehabilitation on these facades, and though the elaboration of the decision-support model, where several solutions are recommended depending on: if there is a architectural feasibility to apply an external solution throughout (if the building do not have architectural and heritage value) or in certain places of the façade (corresponding to less visible areas of the facades); if the occurrence of ascending humidity and salt crystallization on the facades is frequent; the typology of the facades; the technically and economically feasible to proceed with an internal thermal insulation solution. Therefore, the goals set to this dissertation were accomplished.

In future researches, it is considered important to deepen and continue this research study, for example through other dissertations, applying this model to more practical cases, in order to validate it more broadly, and including an eventual study focused in more extreme climate zones. Finally, a similar studies to this dissertation, but applied to roofs and glazed areas, are also recommended.

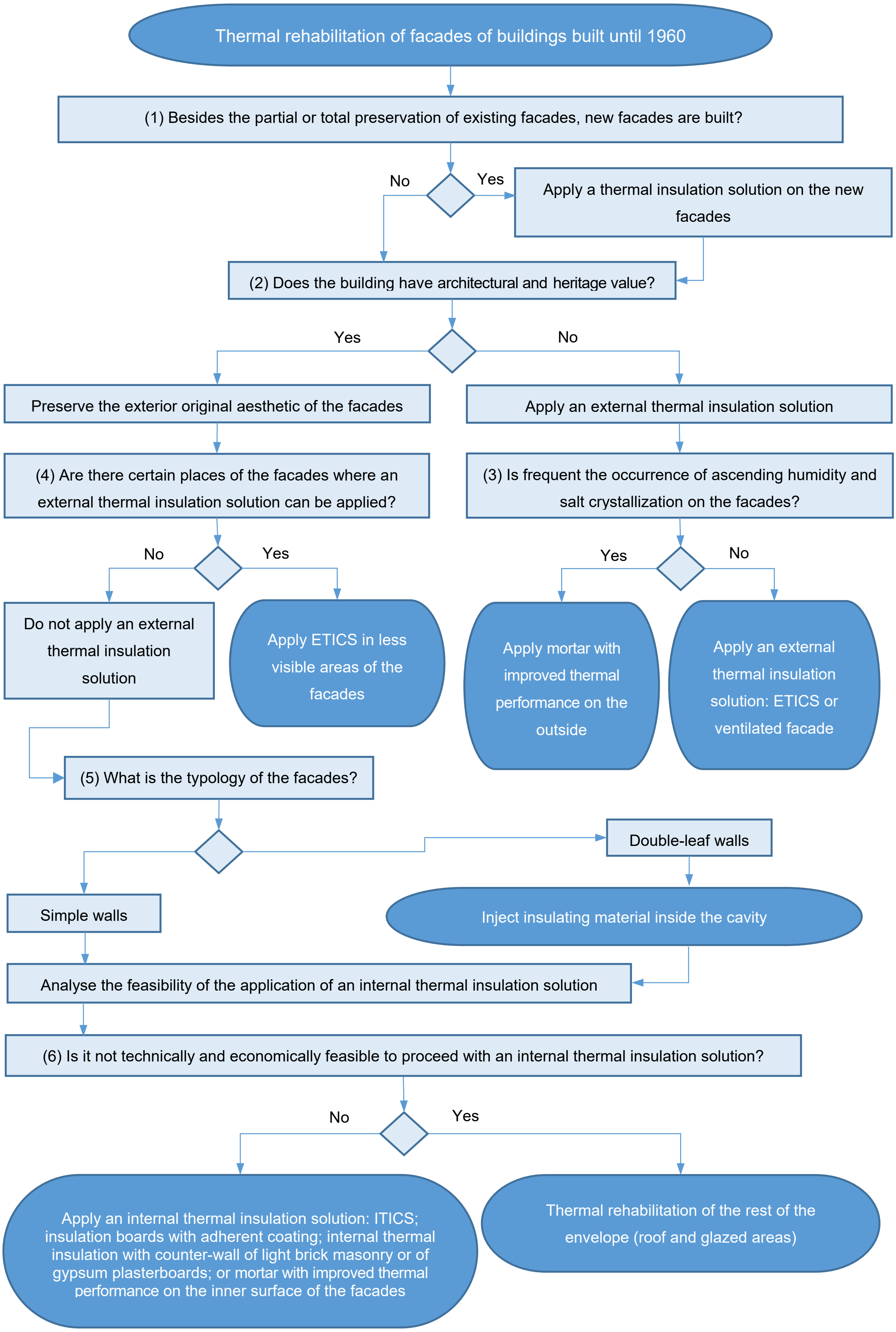

Figure 2: Flowchart to support the thermal rehabilitation of facades of old buildings

Table 5: Detailed information about the critical points of decision of the Flowchart

<table>
<tr><th colspan="2">(1) Besides the partial or total preservation of existing facades, new facades are built?</th></tr>
<tr><td rowspan="2">• In rehabilitations of old buildings, there is sometimes the need to execute new façades, and their contribution to the thermal performance of the envelop must be analysed.</td><td>Yes. → In areas of the envelop where new facades are built, a thermal insulation solution must be included in their building solution. Following, the hypotheses of thermal improvement of existing facades should be analyzed.</td></tr>
<tr><td>No. → Continue to the decision process regarding the measures that should be adopted to improve the thermal performance of the existing façades, which have been preserved.</td></tr>
<tr><th colspan="2">(2) Does the building have architectural and heritage value?</th></tr>
<tr><td rowspan="2">• Is there an intention to preserve the exterior original aesthetic of the facades?
or
• Does the facades have complex architectural features, such as salient elements and window/door frames?</td><td>Yes. → The application of an external thermal retrofitting solution is not recommendable, due to the fact that it could mischaracterize the external aesthetic of the building. Furthermore, its application requires a difficult edge finishing of the system.</td></tr>
<tr><td>No. → The application of an external retrofitting solution is the most appropriate, since it is possible to take advantage of its benefits.</td></tr>
<tr><th colspan="2">(3) Is frequent the occurrence of ascending humidity and salt crystallization on the facades?</th></tr>
<tr><td rowspan="2">• When it occurs, the thermal insulation solution must not create a barrier to the passage of the water with dissolved salt, because that would lead to the creation of a tension field between the wall and the thermal insulation solution, compromising the durability of the insulation material and the system´s adherence to the wall.</td><td>Yes. → The application of mortar with improved thermal performance is several times recommended for this particular case. However, this solution has less thermal resistance than the other thermal insulation solutions.</td></tr>
<tr><td>No. → It is recommended the use of a more thermally efficient solution: ETICS or ventilated facade. These are the solutions that allow the correction of the thermal bridges, maintain the thermal inertia of the facades and also provide exterior aesthetic renovation of the facades. The ETICS is a solution more common than the ventilated façade in the rehabilitation field, possibly because the second one has the highest investment cost associated. The choice of the insulating material of the ETICS system is also very important and it should be used materials that are more permeable to the water vapour, such as MW and ICB, for its application in facades of old buildings, because this facades are porous elements, since they are normally made of stone masonry.</td></tr>
<tr><th colspan="2">(4) Are there certain places of the facades where an external thermal insulation solution can be applied?</th></tr>
<tr><td>• It is intended to preserve the original aesthetic of the building. The possibility of the application of ETICS in low visible areas of the facades should be analysed, as long as its application does not mischaracterize the building´s architecture.</td><td>Yes. → Application of ETICS in less visible areas of the facades.</td></tr>
<tr><td>• Although ETICS is a very thermally efficient solution, when it is only applied in certain areas of the facades, the thermal behaviour of the rest of the facades is not improved. Therefore, it should be analysed if an internal thermal retrofitting solution offer a better improvement of the thermal behaviour of the facades.</td><td>No. → Do not apply an external thermal insulation solution.</td></tr>
<tr><th colspan="2">(5) What is the typology of the facades?</th></tr>
<tr><td rowspan="2">• If it is not possible to apply an external thermal retrofitting solution, such as ETICS, it should be considered the possibility of the application of another solution, depending on the typology of the façade.</td><td>Double-leaf wall. → It is recommended the analyses of two types of solution. In this case, it is possible to inject insulating material inside the cavity of the wall, preserving the exterior and interior appearance of the façade. However, it is necessary to consider the difficulty of ensuring the efficiency of the filling process of the cavity of the walls. In case of infeasibility of this solution, the possibility of applying thermal insulation through the interior of the façade should be analyzed.</td></tr>
<tr><td>Simple wall. → For this case there are several internal thermal retrofitting solutions, so the feasibility of its application must be examined.</td></tr>
<tr><th colspan="2">(6) Is it not technically and economically feasible to proceed with an internal thermal insulation solution?</th></tr>
<tr><td rowspan="2">• Do the constrains of an internal thermal retrofitting solution, such as the lost of thermal inertia of the facades and the reduction of the useful inner area, override the benefits, such as the increase of thermal resistance of the facades?
or
• The economic limitation prevents its application?</td><td>Yes. → After analysing the advantages and disadvantages, if it is not possible to apply a thermal retrofitting solution on the facades, given the constraints involved, thermal rehabilitation measures should be taken in the remaining envelope (roof and glazed areas).</td></tr>
<tr><td>No. → Apply an internal thermal insulation solution: ITICS; insulation boards with adherent coating; internal thermal insulation with counter-wall of light brick masonry or of gypsum plasterboards; or mortar with improved thermal performance on the inner surface of the facades.</td></tr>
</table>

References

[1] APPLETON, João. ***Rehabilitation of Old Buildings – Pathologies and intervention technologies***. Amadora: Orion Publishing, 2nd Edition, 2011.

[2] Structures Department of LNEC - Earthquake Engineering and Dynamic Structures Core. ***Evolution of building typologies in Portugal.*** Available in http://www-ext.lnec.pt/LNEC/DE/NESDE/divulgacao/evol_tipol.html [Consulted in February 2016].

[3] GUIMARÃES, Miguel. ***Thermal rehabilitation strategies in residential buildings.*** Dissertation to obtain the Master Degree in Construction. Lisbon: IST, 2011.

[4] PINTO, André. ***Thermal Rehabilitation of facades. Case study by numerical simulation.*** Dissertation to obtain the Master Degree in Construction. Porto: FEUP, 2011.

[5] CHO, Soolyeon; MARTINÉZ-MOLINA, Antonio; TORT-AUSINA, Isabel; VIVANCOS, José-Luis. ***Energy efficiency and thermal Comfort in historic buildings: A review.*** *Renewable and Sustainable Energy Reviews*, Vol. 61, p. 70-85, 2016.

[6] Assembly of the Republic. ***Energy Certification of Buildings (SCE), Regulation of Energy Performance of Residential Buildings (SHR) and Regulation of Energy Performance of Buildings Trade and Services (RECS)***, Degree-Law n.º 118/2013 of 20th August § D.L. 1st part – N.º 159 – 4988-- 5004.

[7] Assembly of the Republic. ***Exceptional regime for buildings' rehabilitation***, Degree-Law n.º 53/2014 de 8th April § D.L. 1st part — N.º 69 — 2337 – 2340.

[8] FREITAS, Vasco Peixoto. ***External thermal insulation of facades: reinforced thin plaster on expanded polystyrene - ETICS.*** Maxit – Construction and Renovation Technologies, Lda. Report – HT 191A/02. Porto: 2002.

[9] ADENE. ***Guide of Energy Efficiency.*** Lisbon: ADENE – Agency for Energy, 2012.

[10] FEE - Energy Efficiency Fund. ***Notice for submitting an application to the energy efficiency fund - Building Efficient 2015.*** Lisbon: PNAEE - National Action Plan for Energy Efficiency, 2015.

[11] BRAGA, Ana Marta. PIEDADE, António Canha da; RODRIGUES, António Moret. ***Thermal of buildings.*** Amadora: Orion Publishing, 1st Edition, 2009.

[12] BRITO, Jorge de; FREITAS, Vasco Peixoto; HENRIQUES, Dulce Franco; MOURA, Rita; PINHO, Fernando F. S.; SILVA, Maria João Falcão da. ***Reflection on the strategy for rehabilitation in Portugal.*** Lisbon and Porto: PTPC – Portuguese Technology Platform of Construction, 2015.

[13] SILVA, Vera. ***Guide for rehabilitation - Thermal insulation of current buildings with extruded polystyrene***, Project "Cooperate to Rehabilitate" by InovaDomus. Lisbon: Iberfibran – Extruded polystyrene, SA, 2013.